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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 5 : G01B 11/24	A1	(11) International Publication Number: **WO 92/08104** (43) International Publication Date: 14 May 1992 (14.05.92)

(21) International Application Number: PCT/US91/07995

(22) International Filing Date: 23 October 1991 (23.10.91)

(30) Priority data:
602,475   24 October 1990 (24.10.90)   US
615,447   19 November 1990 (19.11.90)   US

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(81) Designated States: AT (European patent), BE (European patent), CH (European patent), DE (European patent), DK (European patent), ES (European patent), FR (European patent), GB (European patent), GR (European patent), IT (European patent), JP, LU (European patent), NL (European patent), SE (European patent).

Published
With international search report.
Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.

(54) Title: APPARATUS FOR GENERATING SURFACE TOPOGRAPHICAL IMAGES
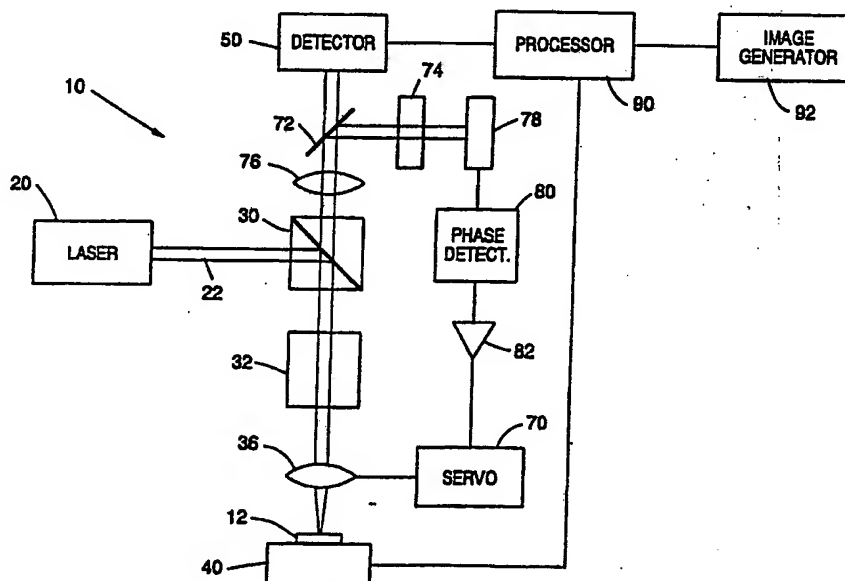
(57) Abstract

An apparatus (10) for generating images of the surface topography of a sample (12) is disclosed. In the apparatus, a probe beam (22) is focused and scanned over the surface of the sample (12). The displacements of the reflected probe beam which are the result of angular deviations in the beam caused by surface features are measured. The displacements are used to generate images of the surface features. The images are derived from displacements either parallel or perpendicular to the direction of the scan. Additional images can be generated using a composite of both displacements.

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APPARATUS FOR GENERATING
SURFACE TOPOGRAPHICAL IMAGES

This application is a continuation-in-part of
prior copending application Serial No. 07/602,475,
5   filed October 24, 1990.

Technical Field

The subject invention relates to a device for
generating surface topographical images. The device
can produce images of angstrom size features and is
10   particularly suitable for analyzing semiconductor
wafers.

Background of the Invention

In the prior art, a number of systems have been
developed to measure variations in the surface
15   topography of various samples. Many of these systems
employ optical measurement techniques which have the
advantage of being both nondestructive and noncontact
approaches. In these devices, a probe beam is
scanned over the surface of the sample. Various
20   techniques are used to detect changes in the probe
beam due to surface irregularities.

One example of a prior art technique can be
found in U.S. Patent No. 4,714,348, issued December
22, 1987 to MaKosch which discloses an
25   interferometric approach. An approach which measures
the amount of light which is scattered from a probe
beam is described in U.S. Patent No. 4,859,062,
issued August 22, 1989 to Thurn et al. In U.S.
Patent No. 4,798,469, issued January 17, 1989 to
30   Burke, an apparatus is disclosed which monitors the
variation in the diameter of a reflected spot to
provide topographical information. The latter
approach relies on the same principles as
autofocusing techniques.

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The subject invention is based on measuring the
angular deviations of a specularly reflected probe
beam that are induced by surface irregularities. The
measurement of angular deviations of a specularly
5   reflected probe beam has been used to evaluate
surface topography. (See for example, U.S. Patents
No. 3,667,846, issued June 6, 1972 to Nater et al.;
No 3,857,737, issued December 31, 1974 to Obenreder;
and No. 4,763,006, issued August 9, 1988 to Rau et
10   al.) It is believed that none of the above cited
systems could be used to evaluate surface
irregularities on the angstrom scale. Moreover, none
of these prior art patents disclosed methods for
generating high resolution visual images of the
15   surface of the sample.
Accordingly, it is an object of the subject
invention to provide an apparatus for measuring the
surface topography of a sample.
It is another object of the subject invention to
20   provide an apparatus for generating images of the
surface topography of a sample.
It is a further object of the subject invention
to provide an apparatus which can measure surface
irregularities on the angstrom scale.
25   It is still another object of the subject
invention to provide an apparatus which can generate
images based on the angular deviation of a probe
beam.
It is still a further object of the subject
30   invention to provide an apparatus which can generate
images based on the angular deviation of a probe beam
which occurs in the direction of the scan of the
probe beam.
It is still another object of the subject
35   invention to provide an apparatus which can generate
images based on the angular deviation of a probe beam

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which occurs perpendicular to the direction of the
scan of the probe beam.

It is still a further object of the subject
invention to provide an apparatus which can generate
5   images based on various composites of the angular
deviation of a probe beam which occur both parallel
and perpendicular to the direction of the scan of the
probe beam.

It is still another object of the subject
10   invention to provide an apparatus which can generate
an image which displays the absolute height of
surface features on the sample.

Summary of the Invention

In accordance with these and many other objects
15   the subject invention includes laser for generating a
collimated probe beam. A high numerical aperture
lens is used to focus the probe beam onto the surface
of the sample with a spot size of about one micron in
diameter. The reflected probe beam is directed to a
20   photodetector which can monitor changes in position
of the beam that are result of angular deviations
produced by surface features of the sample.

A high precision stage is provided to scan the
sample with respect to the probe beam. Surface
25   features will induce angular deviations of the beam
both parallel and perpendicular to the direction of
the scan. The angular deviations are converted to
lateral displacements when the reflected probe beam
passes back up through the lens. These lateral
30   deviations are measured by the photodetector.

Images of the surface are created using
displacement measurements which are either parallel
or perpendicular to the direction of the scan.
Images can also be created using various combinations
35   of both orthogonal displacements. As discussed in

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detail below, different combinations can be used to enhance different kind of topological features.

An image of the absolute height of surface features can also be generated by integrating the
5   angular deviation measurements with respect to incremental positions of the scanned probe beam.

Further objects and advantages of the subject invention will become apparent from the following detailed description, taken in conjunction with the
10   drawings in which:

Brief Description of the Drawings

Figure 1 is a schematic diagram of an apparatus constructed in accordance with the subject invention.

Figure 2 is a bottom plan view of a quad cell
15   photodetector.

Figures 3a through 3d illustrate the interaction between the probe beam and a surface feature of the sample.

Figure 4 is a perspective view of a surface
20   feature which runs along one of the scan directions.

Figures 5a through 5c are simplified illustrations of the images which can be generated with the subject system.

Figures 6 through 10 are photographs of various
25   images taken of the surface of a sample highlighting one particular surface feature.

Figure 6 is an image which is generated with the subject system using angular deviation measurements parallel to the direction of the scan.

30   Figure 7 is an image which is generated with the subject system using angular deviation measurements perpendicular to the direction of the scan.

Figure 8 is an image which is generated with the subject system wherein angular deviation measurements

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both parallel and perpendicular to the direction of
the scan are combined.

Figure 9 is an image which is generated with the
subject system wherein angular deviation measurements
both parallel and perpendicular to the direction of
the scan are combined in a different manner.

Figure 10 is an image which is generated with
the subject system wherein angular deviation
measurements both parallel and perpendicular to the
direction of the scan are combined in the same manner
as in Figure 9 and then inverted.

Figure 11 is a line scan which is generated with
the subject system using angular deviation
measurements to illustrate absolute height
variations.

Figure 12 is a diagram illustrating an approach
for generating a two dimensional image which displays
absolute height information.

Detailed Description of the Preferred Embodiment

Referring to Figure 1, there is illustrated an
apparatus 10 for detecting topological features on
the surface of a sample 12 and generating images of
those features. The apparatus includes a laser 20
for generating a probe beam 22. In the preferred
embodiment, laser 20 is a linearly polarized HeNe
laser generating an output beam 22 of 633 nm having a
5 mW power.

The probe beam 22 is directed downwardly by a
polarizing beam splitter 30 through a quarter wave
plate 32. The beam then passes through lens 36 and
onto the surface of the sample 12 with 3 mW of
incident power.

In accordance with the subject invention, lens
36 is a powerful microscope objective having a high

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numerical aperture (NA). The NA of the lens should
be at least 0.5 and is preferably on the order of
0.95. This diffraction limited optical arrangement
is arranged to produce spot sizes on the sample
5   having a diameter on the order of one micron. In the
preferred embodiment, the spot size is set to 0.8
microns. The lens is spaced from the surface of the
sample an amount substantially equal to its focal
length. This position is maintained using an
10 autofocus mechanism discussed in greater detail
below.

A stage 40 is provided to support the sample 12
and for scanning the sample with respect to the probe
beam in two orthogonal directions. In the preferred
15 embodiment, a dc servo stage is used, manufactured by
Kensington Labs. The stage utilizes an optically
encoded feedback control system so movements in
either the X or Y direction can be controlled to
within 500 angstroms. This stage also provides for
20 rotation of the sample.

The reflected probe beam will pass back up
through lens 36 and quarter wave plate 32. The two
passes through the quarter waveplate 32 function to
rotate the polarization of the beam a full 90 degrees
25 so that when the beam reaches splitter 30 it will
pass therethrough to fall on photodetector 50.
Photodetector 50 is of the type which can detect
displacements of the probe beam. A photodetector
having an two dimensional array of detecting elements
30 could be used. In the illustrated embodiment, a quad
cell detector is used and the optics are arranged
such that the probe beam will underfill the detector.

The use and operation of quad cell detectors is
well known in the art. The surface of the quad cell
35 detector is illustrated in Figure 2. Briefly, each
of the four quadrants (52, 53, 54, 55) generates

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separate voltage levels proportional to the power of
the light falling on that segment. When the beam 22
is centered, each of the four quadrants will generate
the same voltage. When the position of the beam
5   moves from the center (shown schematically as 22a),
the voltage levels will vary and position information
can be determined.

For example, to determine the displacement of
the beam in the X direction, the sum of the output
10   voltage generated by the two quadrants (52, 55) on
the left side of Figure 2 would be subtracted from
the sum of the output voltage generated by the two
quadrants (53, 54) on the right side of the Figure.
The displacement in the Y direction would be
15   determined in a similar manner comparing the outputs
from the top two quadrants (52, 53) with the bottom
two quadrants (54, 55). In the preferred embodiment,
the difference voltages are divided by the sum of the
voltages of all the quadrants to normalize the
20   result.

Figures 3a through 3d illustrate how angular
deviations of the beam due to changes in surface
topography are converted into lateral displacements
of the beam at the detector. As shown in Figure 3a,
25   when the beam is reflected off a flat surface, it
will pass back through the center of the lens 36 and
strike the detector at the center. As the probe beam
is scanned across a hillock 60 (in the X direction),
the beam will deviate angularly backwards (negative
30   X), parallel to the direction of the scan as shown in
Figure 3b. Since the surface of the sample is
substantially in the focal plane of the lens, the
reflected beam will be redirected by the lens along a
path parallel to but laterally displaced from the
35   incoming probe beam. The amount of negative
displacement is proportional to the local slope of

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the surface feature 60. By monitoring the extent of
this displacement, the slope of the surface feature
can be determined.

5   Figure 3c illustrates that at the crest of the
hillock, where the slope is zero, there will be no
displacement and the beam will be once again centered
on the detector. As the scan continues, the angle of
the beam will again deviate in a plane parallel to
the direction of the scan but in a forward sense. As
10   can be seen, a positive lateral displacement will
occur proportional to the slope of the feature but
have an opposite sign (positive X). Using this
convention, a feature which initially produces a
negative displacement followed by a positive
15   displacement will be feature which is raised from the
surface. In contrast, a depression or hole will
characteristically produce an initial displacement
of the probe beam in the positive direction and then
a displacement in the negative direction (with an
20   intermediate, zero displacement).

It should be noted that the assignee of the
subject invention has previously developed an optical
system for measuring the angular displacements of the
sample surface induced by and in phase with an
25   intensity modulated pump laser. This system is
described in U.S. Patent Nos. 45,521,118 and
4,522,510, incorporated herein by reference. In the
latter system, the intensity modulated pump laser
created periodic angular surface changes at the
30   surface of the sample. The extent of those periodic
angular surface changes could be analyzed to evaluate
surface and subsurface features of the sample. The
latter system was not operated in a manner to measure
existing topographical features.

35   Figure 3 illustrates the angular deviation of
the probe in only the X axis, parallel to the

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direction of the scan. If the feature 60 were
symmetrical about the vertical direction, the
magnitude of the displacements in the Y axis would be
the same. However, many features are asymmetric.

5   More importantly, in semiconductor samples, some
features tend to have symmetries that lie along one
of the two axes. Such a feature is shown in Figure 4
wherein a trough is shown to run along the Y-axis.
As noted above, in a scan of a depression along the X

10   axis, the beam will first be displaced in a direction
forward of the scan direction (as shown in the
Figure) and thereafter will return to zero and then
be displaced negatively. However, the slope of the
feature in the Y direction remains constant.

15   Therefore, any scan in the Y direction will not
produce any angular deviation of the probe beam in
that direction and therefore will be reflected back
through the lens 36 with no displacement in the Y
direction as shown in Figure 4. For this reason, it

20   is desirable to be able to generate images of a
sample in both the X and Y directions and images that
are based on a combination of both signals so that
all features can be imaged.

       Having described the basics of the system, some

25   additional details of the subject apparatus 10 will
now be discussed. For example, as noted above, the
lens 36 is maintained a distance from the surface of
the sample an amount substantially equal to the focal
length of the lens. In the case of the preferred

30   0.95 NA lens, this distance is about 300 microns.
This distance is maintained to less than one tenth of
a micron through the use of an autofocus mechanism.

       The autofocus mechanism includes a servo motor
70 for varying the vertical position of the lens 36.

35   The servo is driven by an analog detection loop which
determines if the lens 36 is properly focusing the

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probe beam. As seen in Figure 1, a partially
reflective mirror 72 picks off a small portion of the
reflected probe beam and directs it to a chopper
wheel 74. A lens 76 is positioned in the path of the
5   reflected probe beam such that the chopper wheel 74
is in the focal plane of the lens. The light passing
the chopper wheel 74 is imaged on a split cell
photodetector 78. If the lens 36 is out of focus,
there will be a phase difference in the light
10   striking the two sides of the split cell 78 which is
detected by a phase detector 80. The phase
difference is used as an input to an amplifier 82
which in turn drives the servo. This approach to
autofocusing is known as automated Foucault testing.
15   It should be noted that the deviations in the sample
which effect the movement of lens 36 are several
orders of magnitude greater than the surface features
which are to be imaged.

As noted above, the output from quad cell
20   detector can be used to generate images of the
surface topography of the sample. This output can be
combined in various ways to achieve different
results. The combination process can be performed in
a processor 90 and then sent to an image generation
25   apparatus 92. The imager 92 can be a video monitor
or video hard copy printer.

In the preferred method of the subject
invention, the probe beam is scanned across the
sample using the stage along a plurality of parallel
30   lines. For convenience, the direction of the scan
can be referred to as the X direction.

Typically, the scan will move across a first
line taking measurements at discrete intervals. The
spacing between the intervals can be adjusted from
35   500 angstroms to 16,000 angstroms. To maintain the
desired resolution, the increments utilized should be

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2000 angstroms or less. At the end of the scan line,
the sample is shifted over one increment in a
direction perpendicular to the scan line and a new
scan is started. If the smallest measurement

5   increment is chosen, a magnification of 13,600 times
can be achieved. In practice, features with a height
in the range of a few crystallographic dimensions
have been clearly observed. For example, a slip line
in a silicon wafer approximately 8 angstroms in

10   height, which created a slope of 0.015 degrees over a
linear distance of 3 microns was observed.

       Scans can be executed over regions of different
sizes. The preferred embodiment is programmed to
generate images ranging from 12 square microns to 800

15   square microns.

       As noted above, the displacement of the probe
beam along the surface of the detector is
proportional to the slope of the surface feature on
the sample. This relationship holds true for slopes

20   which do not exceed about 16 degrees. For steeper
slopes, the relationship loses its linearity and some
additional calibration may be necessary. In any
case, any scan should begin on a flat surface to
insure that the data is properly interpreted.

25   Figures 5a though 5c are simplified
illustrations of basic scans of three different
features which are obtained using signals either
parallel or perpendicular to the scan (X) direction.
In these figures, the imager is programmed such that

30   a zero signal or no displacement will be represented
by the middle of a grey scale. As the displacement
(and slope of the feature) increases in a positive
direction, the brightness of the image is increased
with maximum positive displacement being depicted as

35   white. Conversely, maximum negative displacement is
depicted as black.

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The above described convention is useful for
standard black and white video images. However,
various other composition variables, such as color,
could be used to illustrate variations in surface
5   topography.

Figure 5a illustrates the images which would be
generated of a hillock using this convention. As
noted above in the case of a hillock, the signals
parallel to the direction of the scan (X direction)
10   will first have a large negative value (dark) move to
neutral and then increase to a maximum positive
value. This convention is not unlike having a light
source illuminate the feature from the top of the
figure. The displacements of the beam which are
15   perpendicular to the scan direction (Y direction)
will generate an image where the illumination source
appears to be from the left. The illumination
analogy applies for each of the Figures and is useful
in interpreting the images.

20   Figure 5b shows the images generated from the
parallel (X) and perpendicular (Y) signals when
scanning a pit or depression in the sample surface.
It should be noted that the shading patterns are
reversed from Figure 5a. Figure 5c illustrates the
25   images that would be generated from a notch or
depression at the edge of the sample.

Figures 6 through 11 are photographs of actual
images taken with the device of the subject
invention. The surface feature imaged consists of an
30   engraved letter "C" enclosed within an engraved
octagon design. The octagon design is 100 microns
across and the engravings have a depth of 0.1 microns
(1000 angstroms). The scanning increment was set to
4000 angstroms. As each of these photographs are
35   reviewed, it will be observed that various features

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are enhanced or suppressed depending upon the signals
that are processed. The images

Figure 6 is an image of the feature using
signals generated from displacements parallel to the

5   direction of the scan (X direction). As noted above,
this convention tends to produce images where a light
source appears to illuminate the feature from the top
of the image. It should also be noted that the left
and right hand sides of the octagon and the left hand

10   side of the letter "C" are suppressed. This result
occurs because the slope of these features is
constant along the axis parallel to the scan.

Figure 7 is an image based on beam displacement
in a direction perpendicular to the scan (Y

15   direction). In this image, the top and bottom of
both the octagon and letter "C" are suppressed since
these features do not change slope in the Y
direction.

Since many surface features in real samples

20   occur along one of the two perpendicular directions,
additional images are desirable. Figure 8
illustrates one of those images. In Figure 8, the
displacements in both the X and Y direction are
summed and then plotted. This approach has the

25   effect of shifting the source of illumination 45
degrees so that all of the X and Y features are
enhanced. It should be noted that some of the angled
portions of the feature are less prominent.

Various linear combinations of the X and Y

30   displacements signals can be used to make the
illumination appear to come from any azimuthal angle.
One approach would be to combine the signals in
accordance with equation (1) below.

(1)   Image value = $X \cos\theta + Y \sin\theta$

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where θ is the desired azimuthal angle. Note that
when θ is zero degrees, the image generated will be
like that shown in Figure 6, whereas when θ is 90
degrees, the image generated will be like Figure 7.

5   Still another imaging approach is illustrated in
Figure 9. In this approach the value for the
contrast signal (R) at each point in the image is
arrived at using the following formula:

(2) $R = \sqrt{X^2 + Y^2}$.

10

As can be appreciated, this formula eliminates the
sign (+ or -) from the data and produces an absolute
value of the displacement or slope of the feature.
With respect to the image, the steeper the feature,
15   the more it will be illuminated, regardless of
whether it is a down slope or an up slope. This type
of image is desirable when one wants to obtain an
overall picture of the variations in surface
topography without regard to the type of feature
20   being imaged.

The data points used to generate the image in
Figure 10 are obtained by first calculating the value
of R as set forth above in equation 2. Thereafter,
this value is simply inverted so that the highest
25   values are given the darkest color and the lowest
values the brightest color. Similar to Figure 9,
this image also gives an overall picture of
variations in surface topography. However, this
image has the added advantage in that it is more
30   consistent with human observation in standard
lighting conditions wherein flat areas are brightly
illuminated and slopes tend to be shaded.

The subject invention can be further used to
determine the absolute value of the height of a
35   feature. As noted above, the displacements in the

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beam can be converted directly into the slope of the
surface. Height information can be determined by
integrating this slope information with respect to
the increments between data points. As noted above,
5   in the preferred embodiment, the stage is typically
moved in increments that range from 500 angstroms to
2000 angstroms. Using these small increments for the
integration, extremely accurate height information
can be generated.

10   Figure 11 is a graph which gives height
information with respect to the position of the beam
on the sample along a single scan line. An image
similar to Figures 6 through 10 could be generated
from multiple parallel line scans.

15   In order to generate a two dimensional image
which displays absolute vertical height information,
both X and Y angular deviation signals are required.
This requirement can best be appreciated by referring
to Figure 12. Figure 12 is a schematic illustration
20   of a rectangular scan area on the surface of the
sample. Data point 93 is located at point X_1, Y_1,
within the scanned region.

            In order to determine the height of location 93
with respect to starting point 94 (X_0, Y_0) the slope
25   signals along both the X and Y directions must be
considered since surface changes in both directions
contribute to the height Z of data point 93.
Accordingly, to arrive at a height Z, the first step
is to integrate the individual displacement (slope)
30   measurements along the X axis from point 94 to point
95 (X_1, Y_0) as shown in equation (3).

$$(3) \qquad \int_{X_0}^{X_1} \text{X displacement} \Big|_{Y = Y_0}$$

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The next step is to integrate the slope measurements along the Y axis, from point 95 to point 93 as shown in equation (4).

5   (4) $\int_{Y_0}^{Y_1}$ Y displacement $\big|_{X = X_1}$

The results from equations (3) and (4) are then summed to give the height of point 93 with respect to the origin at point 94.

In the preferred embodiment, the value can be 10   more accurately determined by performing the complimentary calculations along a path from the starting point 94, to point 96 (X_0, Y_1) and then to point 93 according to formulas (5) and (6) below.

15   (5) $\int_{Y_0}^{Y_1}$ Y displacement $\big|_{X = X_0}$

         (6) $\int_{X_0}^{X_1}$ X displacement $\big|_{Y = Y_1}$

Theoretically, the sum of equations (5) and (6) will equal the sum of equations (3) and (4). In practice, 20   all four of the equations cane be summed and the result divided by two so that any measurement errors are averaged and minimized thereby achieving a more accurate result for the value of Z at point 93.

The subject topographical imaging system has 25   been incorporated into a thermal wave imaging system marketed by Therma-Wave, Inc., the assignee of the subject invention. When used together, the thermal wave and topographical images provide a powerful tool for the analysis of semiconductor IC devices. More 30   particularly, one can compare the images generated of an area of a wafer to determine whether the observable artifacts are caused by either surface and subsurface anomalies.

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In summary, there has been provided an apparatus
for generating images of the surface topography of a
sample. In the apparatus, a probe beam is focused
and scanned over the surface of the sample. The
5   displacements of the reflected probe beam which are
the result of angular deviations in the beam caused
by surface features are measured. The displacements
are used to generate images of the surface features.
The images are derived from displacements either
10 parallel or perpendicular to the direction of the
scan. Additional images can be generated using a
composite of both displacements.

While the subject invention has been described
with reference to a preferred embodiment, various
15 changes and modifications could be made therein, by
one skilled in the art, without varying from the
scope and spirit of the subject invention as defined
by the appended claims.

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CLAIMS

1. An apparatus for generating images of the
surface topography of a sample comprising:

        means for generating a probe beam;

5   means for directing said probe beam onto
the surface of the sample;

        means for scanning the probe beam relative
to the sample;

        means for measuring the angular deviations
10 of the specularly reflected probe beam with
respect to its position on the sample surface,
said angular deviations being induced by
variations in the surface topography of the
sample; and

15   means for generating a visual image of the
surface topography of the sample based on the
measured angular deviations.

2. An apparatus as recited in claim 1 wherein
said means for directing said probe beam onto the
20 surface of the sample is a lens having a numerical
aperture of at least 0.5.

3. An apparatus as recited in claim 1 wherein
said means for directing said probe beam onto the
surface of the sample is a lens having a numerical
25 aperture of at least 0.95.

4. An apparatus as recited in claim 1 wherein
said means for measuring the angular deviations of
the probe beam is defined by a quad cell
photodetector.

30   5. An apparatus as recited in claim 1 wherein
said scanning means scans the probe beam relative to

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the surface of the sample over multiple parallel scan
lines.

    6.   An apparatus as recited in claim 5 wherein
said visual image is generated using angular
deviation measurements which occur parallel to the
direction of the scan.

    7.   An apparatus as recited in claim 5 wherein
said visual image is generated using angular
deviation measurements which occur perpendicular to
the direction of the scan.

    8.   An apparatus as recited in claim 5 wherein
said visual image is generated by using the sum of
the angular deviation measurements which occur both
parallel and perpendicular to the direction of the
scan.

    9.   An apparatus as recited in claim 5 wherein
said visual image is generated by using the square
root of the sum of the squares of the angular
deviation measurements which occur both parallel and
perpendicular to the direction of the scan.

    10.   An apparatus as recited in claim 5 wherein
said visual image is generated by calculating the
square root of the sum of the squares of the angular
deviation measurements which occur both parallel and
perpendicular to the direction of the scan and
inverting the result.

    11.   An apparatus as recited in claim 5 wherein
a visual image of the vertical height variations of
the sample is generated by using data generated by
integrating the angular deviation measurements with

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respect to the incremental positions of the scanned
probe beam.

12. An apparatus as recited in claim 1 wherein
the extent of the angular deviation measurements are
5   depicted in the image by varying a parameter of the
image with respect to the magnitude of the
measurement.

13. An apparatus is recited in claim 12 wherein
the brightness of the image is varied with respect to
10   the magnitude of the angular deviation measurements.

14. An apparatus as recited in claim 13 wherein
a zero angular deviation measurement is depicted by
neutral brightness and positive and negative angular
deviation measurements are depicted by either
15   brighter or darker images.

15. An apparatus as recited in claim 1 wherein
said means for generating a probe beam is a laser.

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16. A method for generating images of the surface topography of a sample comprising the steps of:

5   scanning a probe beam relative to the surface of a sample;

measuring the angular deviations of the specularly reflected probe beam with respect to its position on the sample surface, said angular deviations being induced by variations in the

10   surface topography of the sample ; and

generating a visual image of the surface topography of the sample based on the measured angular deviations.

17. A method as recited in claim 16 wherein the

15   probe beam is scanned relative to the surface of the sample over multiple parallel scan lines.

18. A method as recited in claim 17 wherein said visual image is generated using angular deviation measurements which occur parallel to the

20   direction of the scan.

19. A method as recited in claim 17 wherein said visual image is generated using angular deviation measurements which occur perpendicular to the direction of the scan.

25   20. A method as recited in claim 17 wherein said visual image is generated by using the sum of the angular deviation measurements which occur both parallel and perpendicular to the direction of the scan.

30   21. A method as recited in claim 17 wherein said visual image is generated by using the square

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root of the sum of the squares of the angular
deviation measurements which occur both parallel and
perpendicular to the direction of the scan.

5   22. A method as recited in claim 17 wherein
said visual image is generated by calculating the
square root of the sum of the squares of the angular
deviation measurements which occur both parallel and
perpendicular to the direction of the scan and
inverting the result.

10   23. A method as recited in claim 17 wherein a
visual image of the vertical height variations of the
sample is generated by using data generated by
integrating the angular deviation measurements with
respect to the incremental positions of the scanned
15   probe beam.

           24. A method as recited in claim 16 wherein the
extent of the angular deviation measurements are
depicted in the image by varying a parameter of the
image with respect to the magnitude of the
20   measurement.

           25. A method is recited in claim 24 wherein the
brightness of the image is varied with respect to the
magnitude of the angular deviation measurements.

           26. A method as recited in claim 25 wherein a
25   zero angular deviation measurement is depicted by
neutral brightness and positive and negative angular
deviation measurements are depicted by either
brighter or darker images.
           27. An apparatus for determining the height at
30   a point on the surface of a sample comprising:
                means for generating a probe beam;

means for directing said probe beam onto
the surface of the sample;

means for scanning the probe beam relative
to the sample along a plurality of parallel scan

5   lines;

means for measuring the angular deviations
of the specularly reflected probe beam that
occur both parallel and perpendicular to the
direction of the scan, said angular deviations

10   being induced by variations in the surface
topography of the sample; and

means for calculating the height at a point
on the surface of the sample based on the
measured angular deviations.

15   28. An apparatus as recited in claim 27 wherein
said calculation means functions to integrate the
angular deviation measurements.

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29.   A method for determining the height of a
point on the surface of a sample comprising the steps
of:

5   scanning a probe beam relative to the
surface of a sample along a plurality of
parallel scan lines;

           measuring the angular deviations of the
specularly reflected probe beam that occur both
parallel and perpendicular to the direction of
10   the scan, said angular deviations being induced
by variations in the surface topography of the
sample; and

           calculating the height at a point on the
surface of the sample based on the measured
15   angular deviations.

30.   A method as recited in claim 29 wherein
said calculation step is performed by integrating the
angular deviation measurements.
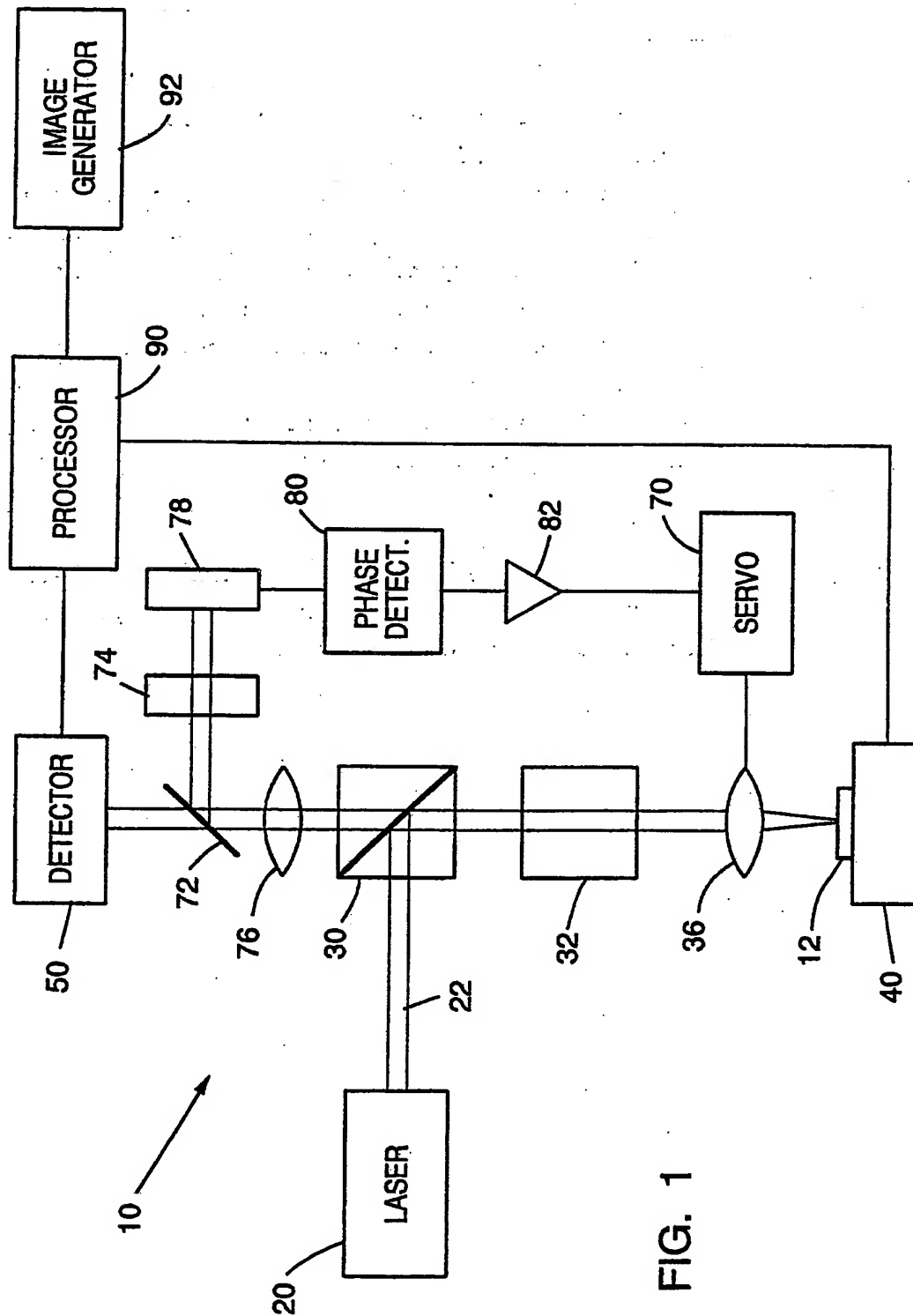
FIG. 1

FIG. 3D

FIG. 3C

FIG. 3B

FIG. 3A

FIG. 4

FIG. 2

FIG. 5

FIG. 6

FIG. 7

FIG. 8

FIG. 9

FIG. 10

96
(x_0, y_1)

93
(x_1, y_1)

94
(x_0, y_0)

95
(x_1, y_0)

FIG. 12

FIG. 11

POSITION (MICRONS)

HEIGHT (Å)

74 Å

INTERNATIONAL SEARCH REPORT

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) 6

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC(5) G01B 11/24
U.S.CL 356/376

II. FIELDS SEARCHED

Minimum Documentation Searched 7

Classification System	Classification Symbols
U.S. Cl.	356/371,376

Documentation Searched other than Minimum Documentation
to the Extent that such Documents are Included in the Fields Searched 8

III. DOCUMENTS CONSIDERED TO BE RELEVANT 9

Category *	Citation of Document, 11 with indication, where appropriate, of the relevant passages 12	Relevant to Claim No. 13
X Y	IBM Technical Disclosure Bulletin, Vol. 13, no. 3 August 1971, R.W. Harrison, "Laser Scanning Surface Profilometer", pages 789-790. (Note lines 7-11 and 17-21).	1,12,15-16, 23-24 1-30
X Y	US,A 3,885,875 ROSENFELD et al. 27 May 1975 (27.05.75) (Note column 4, lines 56-58 and column 6, lines 63-67).	1,5-7,11-12, 15-19,23-24, 27-30 1-30
X Y	US,A 3,975,102 ROSENFELD et al. 17 August 1976 (17.08.76) (Note Figure 8)	1,5-8,11-12 15-20,23-24 27-30 1-30
Y	US,A 4,332,477 SATO 1 June 1982 (01.06.82) (Note Figure 2)	1-30
Y	US,A 4,427,295 NISHIYAMA 24 January 1984 (10.24.84) (Note Figure 1)	1-30
Y	US,A 4,289,400 KUBOTA et al 15 September 1981 (15.09.81) (Note column 5, lines 52-55)	9-10,21-22

* Special categories of cited documents: 10

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

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"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report *
31 January 1992 (31.01.92)	

International Searching Authority	Signature of Authorized Officer
ISA/US	PAULLER NGOC-HO INTERNATIONAL DIVISION R.A. Rosenberger